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Integrated climate change risk assessment and evaluation of adaptation perspective in southern Punjab, Pakistan

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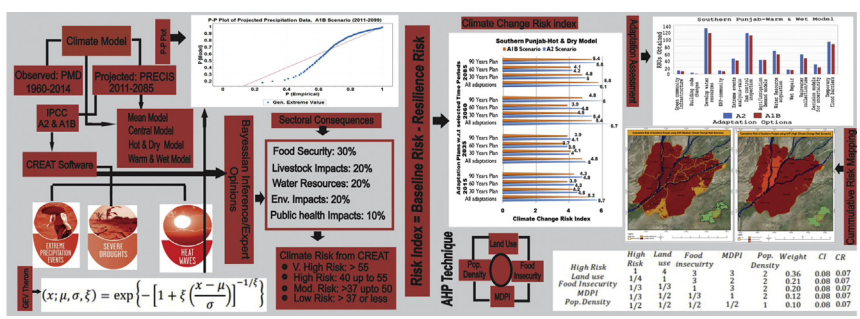
HIGHLIGHTS

- Climate models, time periods & adaptation plans are ensemble to classify climate risk.
- Assessed likelihood approach observed high risk index (>10) for most ensembles.
- Maximum ensembles obtained moderate (37–40) and high (40–55) risk reduction units.
- Muzaffargarh and Rajanpur, 13% of southern Punjab is at very high cumulative risk.
- Development of water resources including flood protection are preferred adaptations.

GRAPHICAL ABSTRACT



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ABSTRACT

Climate change is posing stresses on water resources, food security, population, environment and economy of the southern Punjab. Integrated climate change risk assessment is carried out using assessed likelihood approach for defined mean, hot & dry, central, warm & wet climate models over selected time slices and adaptation plans. Climate models are based on the 5th, 50th & 95th percentiles of PRECIS RCM projections of temperature & precipitation under IPCC A2 & A1B scenarios. Four time slices 2015, 2035, 2065 and 2085 are selected to assess the temporal climate change risk and to evaluate the performance of selected adaptations to reduce climate threats over considered assets. Results are presented in terms of risk indices and risk reduction units (RRUs). In first half of the 21st century, climate change risk will continue to increase from current level and is high (>10) in most of the selected time slices. Maximum ensembles of climate models, time slices and adaptation plans observe moderate (37–40 RRUs) and high (40–55 RRUs) risk class. Cumulative risk has been calculated through integration of sectoral sensitivity e.g. population density, land use, food security and multidimensional poverty to climate change risk class using AHP and overlaying in GIS environment. About 90% and 83% area of southern Punjab is falling in high cumulative risk. About 13% area, comprising Muzaffargarh and Rajanpur district is under very high cumulative risk. Water induced adaptations like development of water resources, dam & flood control protection, temporary flood barriers and water resource acquisition are the preferred and suitable adaptations as these observed >100 RRUs for most of the ensembles. Assessing baseline vulnerability and sectoral sensitivity to climate stimuli are the hot spots requiring priority attention and firm decision making by disaster management authorities and communities residing in southern Punjab.

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1. Introduction

Efforts to map regions which are vulnerable to current or future climate change risks are increased in recent years (de Sherbinin, 2014). Concept of multi-risk assessment has achieved a significant attention in the last decade (EC, 2010; FEMA, 2011; IPCC, 2012; Gallina et al., 2016). There is need of multidimensional and integrated approach to perform multi-risk assessment (Gallina et al., 2016). A multi-risk approach involves a multi-hazard and a multi-vulnerability perspective (Carpignano et al., 2009). Such approach requires understanding of hazards and their possible combinations, exposure and vulnerability of these hazards to different elements at risk and practical measure of potential consequences involved (Crozier and Glade, 2005). In order to perform such challenging task, different approaches (i.e. qualitative, semi-quantitative or quantitative) can be selected (or used in sequence) according to the objectives of the study (Gallina et al., 2016; Aslam et al., 2017). The main barriers in climate change integrated risk assessment and management are unseen inter-dependencies between risks which are attributed in functional, physical, geographical, economic, policy and social mechanisms of that area (Dawson, 2015). Climate change risk assessment is subject to assessing the nature and magnitude of risks which works through such inter-dependencies. Exposure, vulnerability and adapting capacity are assessed by defining linkages between such inter-dependencies. Southern Punjab is selected as area under investigation due to historic evidences of recurring flooding and drought episodes (PDMA, 2012; Aslam et al., 2017). Climate change risks on water resources, agriculture, livestock, food security and economy of southern Punjab are calculated and vulnerability is mapped using suit of integrated techniques.

1.1. Water resources

Punjab is being fed by the Indus Basin Irrigation System (IBIS) through twenty-three canal systems, and several water courses, farm channels and field ditches (GoPb, 2015a). Glacier melt, snowmelt, rainfall and runoff constitute the IBIS flows traversing the Punjab province. Surface water availability is about 820 mm for each irrigated hectare in IBIS which is quite low. It is projected that by 2025, the shortfall of water requirements will be 32% posing serious impacts on IBIS (Qureshi, 2011). Seasonal temperature shifts, variation in snow cover and changing snowfall pattern are directly influencing the runoff of IBIS (Nawaz et al., 2016). The area irrigated by canal water alone has decreased from 7.9 million to 6.9 million ha (Qureshi et al., 2009). The water availability during Rabi season in 2014–15 was estimated at 33.1 million acre feet (MAF), which is 1.8% higher than Rabi of 2013–14 but 9.1% less than the normal availability of 36.4 MAF (MOF, 2015). Pakistan has a total area of 79.61 million hectares, out of which 22.3 million hectares are devoted to farming, within this, 19.12 million hectares are irrigated and 3.67 million hectares are rain fed (Ahmed et al., 2007) which shows that agriculture interventions are heavily dependent on irrigation systems. Low crop yields in irrigated crop zones like southern Punjab is resulting due to inadequate supply of irrigation water. It will be hard to cultivate water intensive crops like rice and sugarcane that require more water (Qureshi et al., 2009). Climate change has implications of water availability in Punjab. About 90% of the population depends on groundwater for their daily domestic needs. Groundwater is extensively pumped in Punjab for agriculture and domestic use (Hussain et al., 2017a, 2017b, 2017c, 2017d). Conjunctive management of surface and ground water in the area is required as sectors like agriculture, livestock, food security, public health and economy are heavily dependent on this valuable resource.

1.2. Agriculture

The most drastic impact of climate change is on developing economies like Pakistan as it is linked to agriculture and a large percentage of populations depend directly on agriculture, agriculture related business and labor (Fischer et al., 2002; Stern, 2006; Cline, 2007; Asif, 2013). Extreme temperature, heavier rains, increase soil erosion through run off and persistent droughts cause vegetation damage with effects on agriculture and sustainable livelihoods (Hisali et al., 2011). Changing growing periods, increased evapo-transpiration, changing irrigation water requirements, reduced availability of irrigation water are resulting due to climate change and posing serious impacts in the form of reduced agricultural and crop productivity (Khan et al., 2016). Variations in temperature and precipitation over southern Punjab are increasing risks for crop production (Amin et al., 2016). Southern Punjab is comprised of two agro-climatic zones based on the cropping pattern, rotation and climate change; low intensity Punjab, and cotton wheat belt. Dera Ghazi Khan, Rajanpur, Muzaffargarh and Layyah are districts with fewer crops due to less developed irrigation facilities and thus are termed as low intensity Punjab. Cotton wheat belt is comprised of districts Sahiwal, Bahawalnagar, Bahawalpur, Rahim Yar Khan, Multan, Vehari, Lodhran, Khanewal and Pakpattan (PARC, 1986; Pinckney, 1989; Malik et al., 2012; Ali et al., 2015).

Around 41–54 °C heat index from May-Sep in the area is resulting induced impacts on agriculture yields/performance (Aslam et al., 2017). Approximately 2–4 °C warmer climate than in 2006 has accelerated the grain formation phase in southern Punjab. Crop yield is reduced due to earlier grain formation with improper grain size and reduced weight (Rasul et al., 2011). In arid, semi-arid and sub-humid zones, the loss of wheat crop yield due to rise in temperature is resulting in shrinkage of the length of crop life cycle (Sultana et al., 2009). An increase of 1 °C temperature from 2008 to 2030 would result in cumulative loss of wheat, cotton and sugarcane up to 0.02%, 13.29% and 13.56% respectively. An increase of 2 °C temperature would result in cumulative loss of wheat, cotton and sugarcane up to 0.75%, 27.98% and 40.09% respectively. For rice crop a gain of 1.85% in production is estimated with increase of 1 °C while it would be 3.95% with increase of 2 °C in the Punjab (Siddiqui et al., 2012). Farmland value is declining in the area with increasing temperatures (Arshad et al., 2016).

In addition to extreme temperatures and drought conditions, heavy precipitation and subsequent floods also poses risks to agriculture yields. Clear shifting of rainfall in the area is directly impacting the agricultural activity (Cheema and Hanif, 2013). Damage to crops, infrastructure and livestock has been reported in southern Punjab from floods (PMD, 2013). Approximately 746.9 thousands hectares crop area was damaged from floods, 2010. A total direct and indirect loss of PKR 156,235 Million was incurred from floods, 2010 (ADB and WB, 2010). In flooding episode of 2014, about 406.6 thousands hectares were damaged due to floods (NDMA, 2014). Loss of USD 34.1 billion has been estimated in agriculture, livestock and fisheries sector of southern Punjab from damage modelling of 2010 floods as base case in 40 year's lapse, which will continue to increase (Aslam et al., 2017). Literature shows that the availability and sufficient supply of good quality inputs, i.e. climate smart/heat resistant varieties, quality pesticides and fertilizers are important factors for effective adaptation to climate risks in the agriculture (Deressa et al., 2005; Bryan et al., 2013). Diversification in livelihoods portfolio, climate smart agriculture, improved food storage and microfinance are proposed interventions in agriculture sector to cope with climate change (NDMA, 2014).

1.3. Livestock

Livestock production which is a global source of food and income is prone to the effects of climate change (Rust and Rust, 2013). Livestock rearing, one of the main livelihood source in southern Punjab, is at high risk due to floods and droughts (Aslam et al., 2017). Mortality and loss of livestock are reported as aftermath of climate extremes. About 5.12 million population of livestock was affected from drought of 1998–2002 curing loss of PKR 5.5 billion (Shafiq and Kakar, 2007). Also damage and loss of shelters and fodder, and emergence of

communicable diseases are common due to climate change in all districts of southern Punjab (Khan et al., 2010). Non availability of feed, heat stress, water supply issues, livestock diseases and disease vectors are the consequences of climate change over livestock sector. Land use changes in the area are occurring at fast pace which may lead to different compositions in animal diets, changes in species number due to depleting rangelands and altered quality of forages (PILDAT, 2016). There is need to devise and implement sector specific adaptations such as timely evacuation in event of disaster, availability of fodder stocks, development of rangelands and livestock surveillance programs in southern Punjab to cope with climate extremes (Aslam et al., 2017). In current investigation this sector is also integrated with other sectors to highlight the risks involved due to climate change.

1.4. Food insecurity

Climate change will alter global as well as regional food production (FAO, 2016). Food shortage of 70 million tons is envisaged by 2025 due to water shortfall (Qureshi, 2011). About 15% households of southern Punjab are measured as food insecure (Bashir et al., 2012). Most of the districts of southern Punjab are either food insecure or standing at bottom level. About 53% of women were found to be food insecure compared with 43% of the total population (Malik et al., 2012). Due to temperature rise excessive melting of Karakoram glacier is predictable to be a 50% increase in first half of the century and then will be reduced by 40% by the second half (Rees and Collins, 2006). This reduction in surface supplies and consequent decrease in groundwater abstraction will have serious impacts on agriculture in the study area. State of food security is deteriorating since 2003, almost half of the population (48.6%) does not have access to adequate food for active and healthy life (Suleri and Haq, 2009). Food security is directly linked with agriculture and economic status which must be considered while performing integrated climate change risk assessments interventions. We have considered food security as a distinct sector and both climate change and cumulative risk assessment for southern Punjab are performed through integrated approach.

1.5. Economic status

Multidimensional poverty index (water, housing sanitation, education, assets, electricity, land, and expenditure) of southern Punjab shows that most of the districts are economically deprived as compare to others in the province (MOPDR, 2015). The food inflation on average basis in July–April of 2014–15, was estimated at 3.6% and nonfood at 5.7%, as against 9.3% and 8.2% in the corresponding period last year (MOF, 2015). After 2010 flooding, wheat and rice prices were increased by 80% and an average person was spending 65% of their income on food items. Percentages of local labor engaged in agriculture, forestry and fishing industry in low intensity Punjab and cotton wheat-belt are 58.7% and 58.9% respectively which shows that the impact on livelihood of population is directly linked with agriculture and climate. Multan and Bahawalpur are the only districts in southern Punjab with >25% urbanization. Sources of income pertaining to livestock in cotton wheat Punjab are 6.68% and only 3.5% in low intensity Punjab. Computed family size in both cotton-wheat belt (8 numbers) and low intensity (8.4 numbers) is quite high corresponding to livelihood sources (Amjad et al., 2008). Due to climate extremes returns and associated damages, the economy of these areas is declining at an alarming rate (SBP, 2002; NDMA, 2007; PDMA, 2008; Aslam et al., 2017). Sectoral development is crucial for uplifting the economic status of southern Punjab by implementation of sector specific climate change adaptations.

1.6. Baseline vulnerability

Existing climate vulnerability index is high in low intensity Punjab and cotton wheat belt, which is computed to 0.62 and 0.44 respectively. Exposure index for both zones stands at 0.54. Sensitivity index stands at 0.54 for low intensity Punjab while it is 0.47 for cotton wheat Punjab (Malik et al., 2012). Further, baseline vulnerability is increasing due to recurring damages and rapid population growth. Reduction in crop and livestock yields, changing cropping calendars and water shortage are the major climate change risks in southern Punjab (Abid et al., 2016). There has been considerable policy interest in the impact of climate change on population dynamics and particularly on migration (Black et al., 2011; de Sherbinin et al., 2011). Population growth rate will reach 1.63% by 2030 with a population of 130 million and by 2050 the numbers will further increase to 181 million (GoPb, 2015a). There would be an increasing demand of agricultural production and water availability to feed rapidly growing population of the area (PARC, 2006). In addition, there would be a decrease in per capita annual availability of wheat from 198 Kg in 2012 to 83 Kg in 2050 because of decrease in rainfall (Tariq et al., 2014). While appraising environmental conditions, highest occurrence of saline water was observed in southern Punjab. Groundwater quality is depleting due to extensive agricultural interventions which are random and poorly managed (Hussain et al., 2016a, 2016b, 2017a). There is no solid waste collection and disposal system in 93% rural areas of Punjab province (GoPb, 2015a). Conversion rate of arable lands into urban and industrial is very high. Built urban environment is heavily disturbed due to climate change, increased pollution, poor water quality and waste management. The rural environment is impacted by loss of agriculture and livestock due to floods, deforestation due to droughts, reductions in crop yields due to extreme temperature which resulted in low income gains because of these impacts (MOCC, 2013; GoPb, 2015b). Both urban and rural areas are lacking adaptation capacity resulting in increased vulnerability (Suleri and Haq, 2009; Malik et al., 2012).

In a nut shell, it is evident that the situation is getting worse due to increasing stress of climate change on water resources, food security, population, environment and economy of southern Punjab. There is pressing need to integrate climate change information into a risk assessment framework to devise right climate change resilience plan. In this paper an effort has been made to define and correlate interdependencies among population, food security, water resources, agriculture, livestock, land use and economic status of the southern Punjab. Integrated climate change risk assessment is carried out which requires number of attributes to be considered in designing specific experiment or analysis interventions. A suite of methods and tools are used to achieve the desired results. For this, climate projections (IPCC A2 & A1B scenarios) that predict the future climate of the area are selected. Climate model comprising of mean, 5th, 50th and 95th percentiles of temperature and precipitation are characterized which precisely represent future climate conditions of southern Punjab. Temporal scope of the current investigation is covering early (2015), mid (2035) and late (2065 & 2085) years of 21st century. P-P plots of climate data are developed using Generalized Extreme Value (GEVs) theorem. Sectoral consequences weighting and assets threat coupling is estimated through Bayesian inference i.e. combining expert opinion with historical data, which is extensively used in climate change impact studies. Both the climate data input and sector consequences are integrated in US EPA Climate Resilience Evaluation and Awareness Tool (CREAT) software (see Section 2.2). In this investigation, the interdependencies of climate models, time periods and adaptation plans of southern Punjab are highlighted in the form of risk indices and comparison is presented. Both baseline climate change risk and risk after resilience are calculated and tabulated. A suite of twelve adaptations that are capable of building climate resilience in selected sectors are included in the assessment. Adaptations are compared and prioritized on the basis of RRUs obtained by individual adaptation against climate model in a specific time period. Scenario based comparison is also presented to evaluate performance of adaptations under certain climatic and socio-economic conditions.

In order to integrate sectoral climate risks, investigation is further extended to cumulative risk assessment through analytical hierarchy

process. CREAT provided climate change risk classes are overlaid with population density, food insecurity, land use and MDPI and results are presented graphically. Ensembles of climate models, time periods and adaptations falling under low, moderate, high, and very high cumulative risk categories are extracted and presented in this paper. Sector specific baseline data of southern Punjab is presented in Table 1.

2. Material and methods

Climate change risk assessment is performed under likelihood assessed approach for IPCC A2 and A1B scenarios and then the performance of selected adaptations is evaluated. Both scenarios are selected instead of IPCC AR5 Representative Concentration Pathways (RCPs) due to their strong emphasis on socio-economic development, climate policy and climate risk involved. At current stage, RCPs are not fully integrated scenarios (i.e. not a complete package of socio-economic emission and climate projections and don't include direct impact on land use. RCPs are not based on socio-economic storylines and are not necessarily more capable of representing future developments than the SRES scenarios (Cubasch et al., 2013). Methods used in this assessment are comprised of tracking of extreme climatic events through GEVs distribution fitting over time series of climate data, preparation of risk assessment framework for CREAT software and cumulative risk assessment in GIS environment. Use of GEVs, sectoral consequence weighting through Bayesian inference, analysis of quantitative risk assessment in terms of risk reduction units (RRUs) and application of analytical hierarchy process (AHP) for cumulative risk assessment in GIS are both qualitative and quantitative techniques used to accomplish objectives of investigation. Such suit of methods is first of its kind and not used earlier for sector specific integrated climate change risk assessment for southern Punjab. Selected integrated climate change risk assessment is comprised of designing climate models, selection of time periods, consequence weighting on sectors, identification of assets considered and threats involved and performance evaluation of selected adaptations. Climate change risk assessment practitioners use different techniques, therefore selected methods and obtained results are not subjected to comparison. The reason of this limitation is perhaps the availability of number of choices in risk assessment techniques. However, such type of assessments can be appraised on the basis of partial similarities in the selected methods. Climate change risk assessments methods similar to this study has been practiced by; IDB, 2016; Molarius et al., 2015 for Finland; Komendantova et al., 2013; Shao-Hong et al., 2012 for China; Marzocchi et al., 2009 for Italy; Dilley et al., 2005 and UNDP, 2004. Schematic illustration of methodology is provided in Fig. 1.

2.1. Statistical analysis of PRECIS RCM data

Evaluation of PRECIS RCM modelled data under IPCC A2 and A1B scenarios in southern Punjab reveals that monthly mean temperature is 30 °C under A2 scenario, 2.4 °C higher than A1B which is 27.6 °C in defined time slices. Monthly mean precipitation under A2 scenario ranges from 12 to 15 mm and for A1B scenario it ranges from 15 to 19 mm (Aslam et al., 2017). There is decreasing trend of annual north-south rainfall patterns and amounts in arid regions (Hussain et al., 2018). Observed past climate data (1960–2014) and projected climate data (2011–2085) of PRECIS RCM for A2 and A1B scenario are statistically processed to obtain means, percentiles and generalized extreme values. Generalized Extreme Values (GEVs) are obtained to track climate extreme events over defined time periods. GEVs are calculated using the exceedance probabilities from observed precipitation time series (i.e. fractions of observations over a series of event magnitudes) and fit to the below;

$$(x;\mu,\sigma,\xi) = \exp\left\{-\left[1+\xi\left(\frac{x-\mu}{\sigma}\right)\right]^{-1/\xi}\right\}$$

where x is the event magnitude, ξ is the shape parameter, σ is the scale parameter and μ is the location parameter.

P-P plots of observed and projected precipitation data are shown in Figs. 2 to 4.

Linear P-P distribution shows that climate change and occurrence of climate extreme event is a dynamic process in the study area and GEVs has normal distributions and in agreement with observed climate anomalies.

Skewness of GEVs in both A2 scenario (Fig. 3) and A1B scenario (Fig. 4) has a remarkable difference which indicates that under both scenarios incidence of climate extreme events have different frequencies and intensities.

2.2. Climate Resilience Evaluation and Awareness Tool (CREAT) version 2.0

Climate Resilience Evaluation and Awareness Tool (CREAT) developed by US EPA is used for climate change risk assessment and calculations of risk indices and risk reduction units (RRUs). The tool utilized both quantitative and qualitative approaches to calculate baseline and resilience risk (US EPA, 2012). CREAT has been extensively used by various institutes in United States for climate change risk assessment and resilience evaluation. It has been utilized; by East Bay Municipal District in Oakland for future climate conditions; by Southern Monmouth Regional Sewerage Authority in New Jersey and city of Poughkeepsie in New York for storm surges; by Southern Nevada Water Authority in Las

Table 1
Sector specific baseline analysis of southern Punjab for cumulative risk assessment.

District name	Population density (persons/km^2) (BOS, 2013)	Food insecure population (% age) (Suleri and Haq, 2009)	MDPI (MOPDR, 2015)	Land use (approximate %age area) (MOE/NARC, 2009)
Sahiwal	731	33.80	0.14	Agri:92%, bare soil:2%, forest:1%, waste land:1%, range land: 2%, settlements: 2%
Bahawalnagar	303	33.3	0.244	Agri:59%, bare soil:4%, rangeland:28%, desert: 8%, waste land:1%
Bahawalpur	137	43.6	0.273	Agri:19%, bare soil:2%, rangeland:25%, desert: 53%, forest:1%
Rahim Yar Khan	373	39	0.289	Agri:48%, bare soil:1%, rangeland:11%, desert: 38%, forest:2%
Multan	1128	44.6	0.173	Agri:85%, bare soil:1%, rangeland:8%, settlement: 4%, forest:2%
Vehari	643	35.4	0.2	Agri:93%, bare soil:4%, rangeland:2%, settlement: 1%
Lodhran	569	39	0.23	Agri:94%, waste land:1%, rangeland:3%, settlement: 1%, desert: 1%
Khanewal	622	39.2	0.189	Agri:92%, forest:2%, rangeland:4%, settlement: 2%
Pakpattan	622	29.9	0.189	Agri:84%, waste land:1%, bare soil:5%, rangeland: 9%, settlement: 1%
Dera Ghazi Khan	197	55	0.351	Agri:22%, exposed rocks:7%, bare soil:33%, rangeland: 35%, water bodies: 2%, forest: 1%
Rajanpur	128	55.3	0.357	Agri:28%, forest:3%, bare soil:39%, exposed rock: 19%, rangeland: 10%, water bodies: 1%,
Muzaffargarh	459	49.9	0.338	Agri:58%, forest:9%, bare soil:3%, rangeland: 27%, water bodies: 3%,
Layyah	179	37.4	0.214	Agri:37%, bare soil:2%, rangeland: 53%, water bodies: 2%, forest: 4% desert: 2%

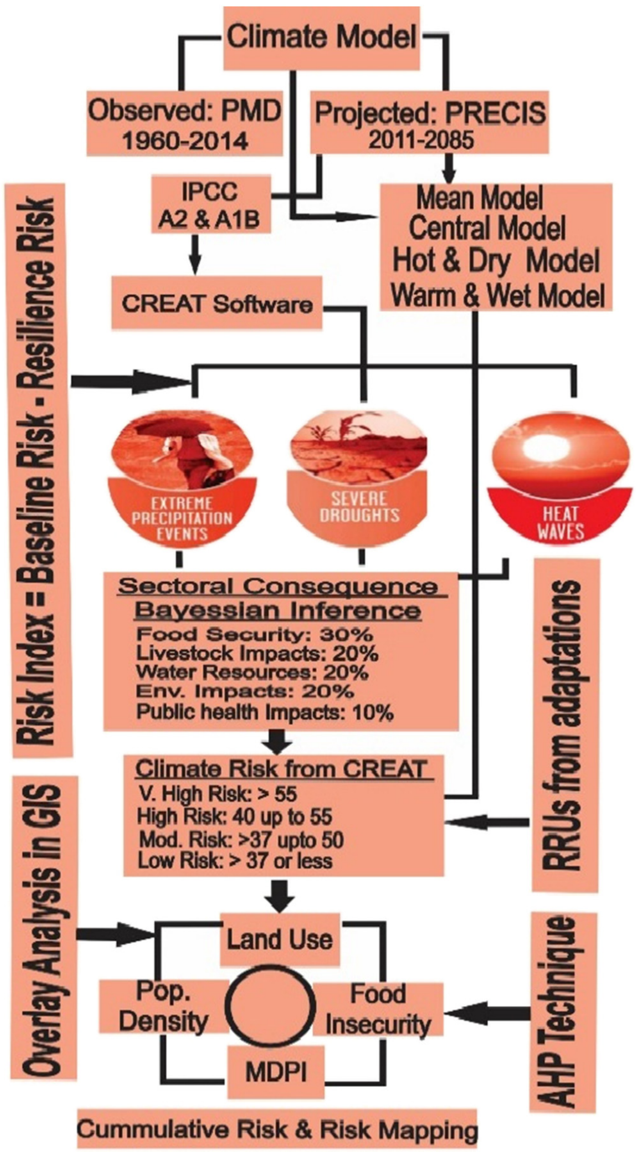


Fig. 1. Schematic illustration of methodological framework.

Vegas for drought, reduced water quality and wildfire; by Camden County Municipal Utility Authority in Camden for flooding; by North Hudson Sewerage Authority in New York for flooding and by Los Osos Water Purveyors in California for salt water intrusion. CREAT provides both conditional likelihood and assessed likelihood approaches for estimating occurrence of specific climatic events. Under current investigation likelihood assessed approach used which aims at the assessment of the likelihood of individual threat occurring as (either 4-very high, 3-high, 2-medium or 1-low) in the time periods assigned to the threat.

2.2.1. Climate models

Observed and projected climate data (temperature and precipitation) of southern Punjab is characterized into following models as input for CREAT software.

Model title	Model specifications
Mean model	Monthly mean-temperature (°C) Monthly total precipitation (in.)
Central model	50th percentile-temperature (°C) 50th percentile-precipitation (in.)
Warm and wet model	5th percentile-temperature (°C) 95th Percentile-Precipitation (in.)
Hot and dry model	95th percentile-temperature (°C) 5th percentile-precipitation (in.)

2.2.2. Time periods

Four time periods 2011–2015, 2011–2035, 2011–2060 and 2011–2085 are selected for assessments of climate-related threats and potential adaptation plans. These time periods are selected to present current, mid and late 21st century for adaptation planning in response to climate stimuli.

2.2.3. Consequence weighting

Consequence of future climate change on food security, livestock, water resources, public health and environment are assessed (see Fig. 1). Consequence value for each sector is calculated using weighted sum approach which allots a combined weighted consequence level score for an asset/threat pair. The weight for each consequence category is based on its relative importance in reducing or increasing overall risk of particular climate change event. Consequence weighting is done through Bayesian inference i.e. combining expert opinion with historical data.

2.2.4. Assets/threats coupling

Natural resources and built infrastructure of the southern Punjab are considered as assets. Identified threats are assigned to relevant assets in

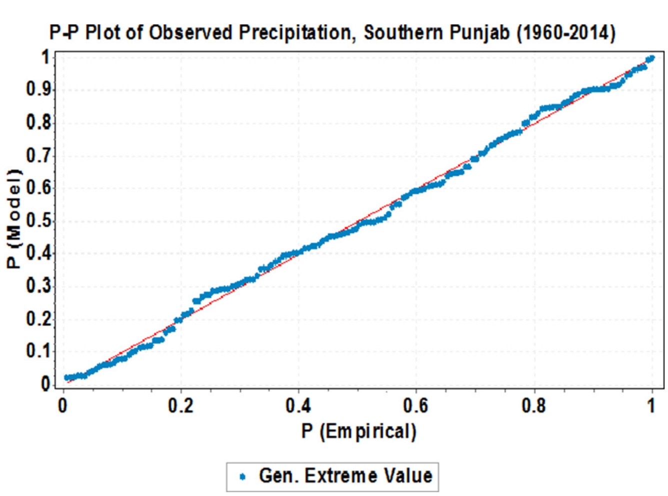


Fig. 2. P-P plot of observed precipitation data.

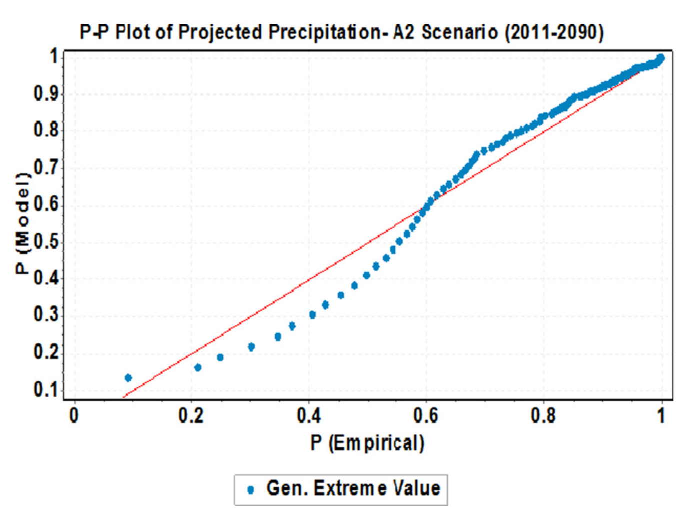


Fig. 3. P-P plot of projected precipitation IPCC A2 scenario.

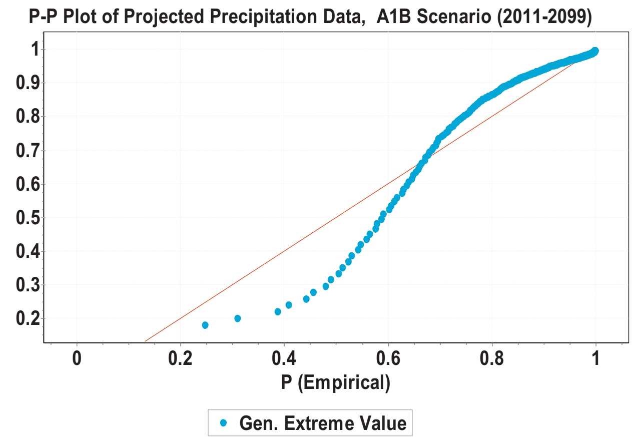


Fig. 4. P-P plot of projected precipitation IPCC A1B scenario.

CREAT environment to generate asset-threat pairs for risk assessment. Assets/threats coupling used in climate change risk assessment is provided below.

Assets considered	Threats assigned
Agricultural land	High flow events
Irrigation network/Infrastructure	Surface water logging
Forested land	Loss of agriculture crops and livestock
Managed species	Changes in agriculture practices
Wetland/ Flood Plain	Changes in energy sector water needs
	Changes in local water demand

2.2.5. Identification of adaptations measures and plans

Existing and potential adaptation measures, which support the development of baseline and resilience assessments respectively, are categorized based on the scope and type of actions required to address particular threat. Measures include actions that modify current practices and those that require new structures or significant changes in operation or practices. A suite of twelve adaptations is selected for individual time period and used during the baseline and resilience risk assessment. Four adaptation plans (30 years, 60 years, 90 years and all adaptations included) are selected to reduce the risks of climatic threats to assigned assets. Adaptation plans are designed using combinations of existing and potential adaptation measures. Each individual adaptation contributes in reducing the risk of selected threats and observed typical value of RRUs during CREAT analysis.

2.2.6. Climate change risk assessment

Climate change risk over southern Punjab is calculated through number of risk reduction units (RRUs) obtained against each climate model in a particular time period and for specific adaptation plan. Baseline and resilience risk assessment for each asset/threat pair is performed in CREAT environment. RRUs are based on change in risk from reduced consequences from each threat attained through implementation of adaptation measures. Baseline risk assessment depicts the climate change resilience achieved using only existing adaptation measures. The resilience risk assessment gauges the increased resilience to future climate change-related threats, considering the addition of potential adaptation measures that could be implemented to reduce the severity of consequences.

$$\text{Climate Change Risk Index} = \text{Baseline risk (RRUs)} - \text{Resilience risk (RRUs)}$$

CREAT provides a default range of RRUs for classification of climate change risk into very high (>55 RRUs), high (40–55 RRUs), moderate (37–40 RRUs) and low (>37 or less RRUs). Ensembles of climate models, time periods and adaptations plans are sorted out into climate change risk classes based on achieved RRUs.

Table 2
Criteria of AHP for climate change risk classes.

a) AHP with CREAT provided low climate change risk

	Low Risk	*Land use*	*Food insecurity*	*MDPI*	*Pop. Density*	*Weight*	*CI*	*CR*
Low Risk	1	3	2	2	2	0.40	0.15	0.14
Land use	1/3	1	2	2	2	0.22	0.15	0.14
Food Insecurity	1/2	1/2	1	3	2	0.16	0.15	0.14
MDPI	1/2	1/2	1/3	1	2	0.11	0.15	0.14
Pop.Density	1/2	1/2	1/3	1/2	1	0.10	0.15	0.14

b) AHP with CREAT provided medium climate change risk

	Med. Risk	*Land use*	*Food insecurity*	*MDPI*	*Pop. Density*	*Weight*	*CI*	*CR*
Medium Risk	1	3	2	3	2	0.39	0.14	0.12
Land use	1/3	1	2	2	2	0.21	0.14	0.12
Food Insecurity	1/2	1/2	1	3	2	0.17	0.14	0.12
MDPI	1/3	1/2	1/3	1	2	0.12	0.14	0.12
Pop.Density	1/2	1/2	1/2	1/2	1	0.10	0.14	0.12

c) AHP with CREAT provided high climate change risk

	High Risk	*Land use*	*Food insecurity*	*MDPI*	*Pop. Density*	*Weight*	*CI*	*CR*
High Risk	1	4	3	3	2	0.36	0.08	0.07
Land use	1/4	1	3	2	2	0.21	0.08	0.07
Food Insecurity	1/3	1/3	1	3	2	0.20	0.08	0.07
MDPI	1/3	1/2	1/3	1	2	0.12	0.08	0.07
Pop.Density	1/2	1/2	1/2	1/2	1	0.10	0.08	0.07

Note:
1: Both layers have equal weight and contribute equally to cumulative risk.
2: One layer has 25% higher weight than other and contribute moderately more to cumulative risk.
3: One layer has 50% higher weight than other and contribute higher to cumulative risk.
4: One layer has 100% higher weight than other and contribute very high to cumulative risk.
CI: Consistency index.
CR: Consistency ratio.

2.3. Cumulative risk assessment-integration of climate change risk into sectors

Cumulative risk is calculated using grid overlay analysis in GIS environment by which layers of CREAT provided climate change risk, population density, land use, multi-dimensional poverty and food security are overlaid (see Table 1). This technique is extensively being practiced for risk mapping e.g. (ECDC, 2012; Ranjitkar et al., 2016; McGranahan et al., 2007). Analytic hierarchy process (AHP) is used as multi-criteria analysis tool to assign weights to considered layers. AHP is a pairwise comparison of all the criteria considered for analysis and has been widely used by many researchers (Nas et al., 2010; Bunruamkaew and Murayam, 2011; Abushnaf et al., 2013; Baidya et al., 2014; Chen, 2016) and others. AHP incorporate several criteria/factors of a problem into a logical hierarchy (Chandio et al., 2011; Ouma and Tateishi, 2014). AHP is quite effective in solving problems of different fields which involves multi criteria using limited available data (Ho, 2008). AHP is being increasingly applied in climate change adaptation and is quite flexible in selection of both tangible and intangible criteria and subcriteria (Bharwani et al., 2013). Climate extremes have been mapped by many researchers using AHP (Lane and Watson, 2010; Choy et al., 2012; Le Cozannet et al., 2013; Chakraborty and Joshi, 2016; Danumah, 2016). Criteria for AHP used to calculate the weight of each climate change risk class over land use, food insecurity, MDPI and population density is presented in Table 2.

3. Results

Risk indices of climate models (mean, hot & dry, central, warm & wet) over time periods (2015, 2035, 2060 and 2085) are calculated against adaptation plans (plan containing all adaptations, 30, 60 and 90 years adaptation plans). High risk index under a particular climate model indicate that a high difference is present between baseline and resilience risk and selected adaptation plan is not quite supportive in achieving climate change resilience. Each risk index value provides a measure of the overall condition before and after adaptation respectively. Baseline risk indicates conditions with existing adaptations and resilience risk indicate conditions after potential adaptations. The difference in baseline and resilience risk is considered as a benefit realized through adaptation (see Tables 4 & 5). Performance of adaptations is assessed in terms of Risk Reduction Units (RRUs) obtained by each adaptation in order to reduce baseline risk. Higher value of RRUs by individual adaptation indicate its effectiveness in achieving climate change resilience. Each adaption observed different RRUs against selected time periods under different climate models. Total RRUs observed by selected climate models for IPCC A2 and A1B scenarios are presented in Table 6. Effectiveness of adaptation measures has been interpreted by comparing the RRUs across packages or scenarios for different plans or different future climate conditions. IPCC A2 and A1B scenario based comparison is presented in this paper, however results can be interpreted and compared within and among climate models, time periods and adaptation plans to accomplish desired objectives.

3.1. Mean climate model

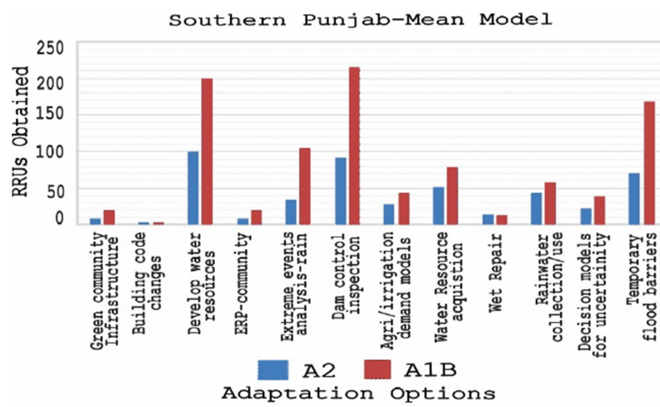


Fig. 6. Adaptation perspective- mean model: Most adaptations observed maximum RRUs for A1B scenario. Dam & flood control inspection observed 216 RRUs for A1B as compare to only 91 RRUs under A2 scenario. Develop water resources is the 2nd preferred adaptation with 200 RRUs for A1B while it may not work well in A2 scenario as achieved only 100 RRUs. Similarly extreme precipitation event analysis stands at 3rd rank with 104 RRUs, and water resource acquisition adaptation with 79 RRUs is at 4th rank under A1B scenario. All adaptations under A2 scenario are not supportive in achieving climate change resilience.

3.2. Hot & dry climate model

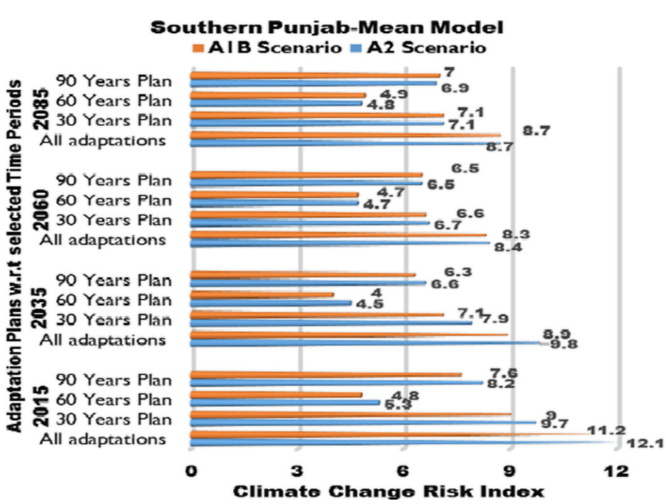


Fig. 5. Climate change risk index - mean model: Maximum risk index is observed against all adaptations in 2015 time slice for both A2 and A1B scenarios which indicate the baseline climate vulnerability is already high. Minimum risk index is obtained by 60 years adaptation plan in 2035 time slice for both A2 and A1B scenarios. There is no considerable difference among risk indices of both scenarios, obtained in all adaptations plans (30, 60, 90 and All adaptations) in all time periods.

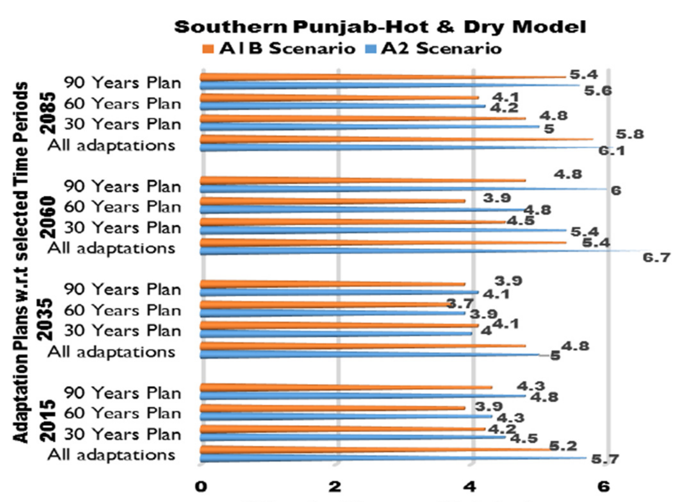


Fig. 7. Climate change risk index-hot & dry model: Maximum risk index is observed by plan including all adaptations in 2060 time slice for A2 scenario and in 2085 for A1B scenario. Minimum risk index is observed by 60 years adaptation plan in 2035 time slice for both A2 & A1B scenarios. There is no reasonable difference among risk indices of both scenarios in all time periods against all adaptations.

3.3. Central climate model

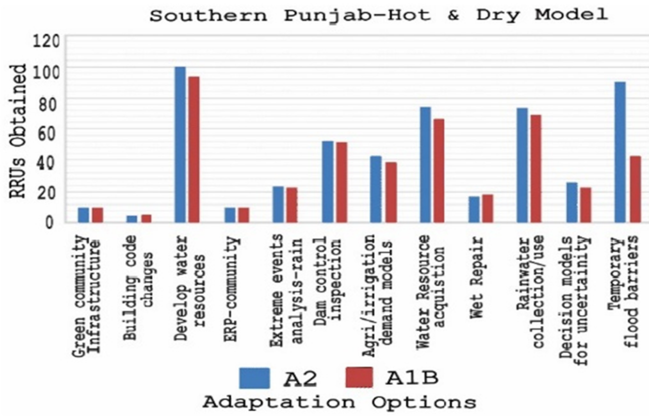


Fig. 8. Adaptation perspective - hot & dry model: Develop water resources (100 RRUs for A2 & 93 RRUs for A1B), water resource acquisition (74 RRUs for A2 & 66 RRUs for A1B) and rain water collection and use (73 RRUs for A2 & 68 RRUs for A1B) can be considered in achiving climate change resilience. All other adaptations observed <50 RRUs and are not preferred adaptations to achieve climate change resilience. Temporary flood barrier has achieved 89 RRUs for A2 scenario which is anomaly and attributable with extreme events aftermath only.

3.4. Warm & wet model

3.5. Cumulative risk assessment using AHP

Cumulative risk is calculated based on analytical hierarchy process in which weight is assigned to CREAT provided climate change risk class and sectors like population density, land use, food insecurity and MDPI of southern Punjab. CREAT computed climate change risk classes

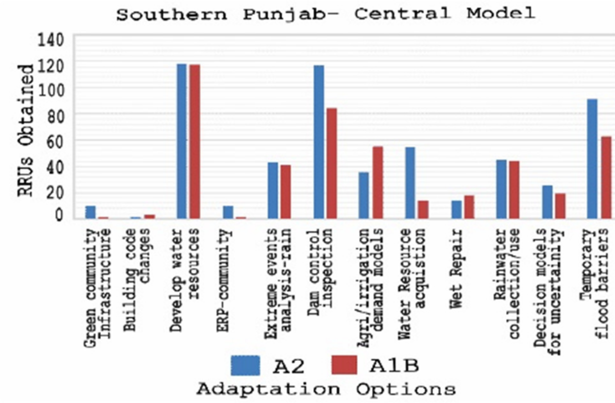


Fig. 10. Adaptation perspective - central model: Develop water resources (118 RRUs) and dam and flood control inspection (116 RRUs) are the most effective adaptations for A2 scenario followed by temporary flood barriers with 91 RRUs. All the other adaptations are not quite effective and must not be prioritized in resilience decision making. Under A1B scenario, except develop water resources all adaptations achieved <100 RRUs. Dam & flood control inspection (89 RRUs),Temporary flood barrier (62 RRUs) and agriculture and irrigation demand model (54 RRUs) are adaptation with medium benefits.

i.e. high (40–55 RRUs), moderate (37–40 RRUs) and low (>37 or less RRUs) are overlaid with sectoral data to compute cumulative risk of southern Punjab. Cumulative risk is categorized as low, moderate, high and very high risk. Percentage of area in southern Punjab under different cumulative risk categories is tabulated as Table 3. Ensembles of climate models, time periods and adaptation plans opting various cumulative risk categories and their spatial distribution over southern Punjab are presented in Figs. 13 to 15.

4. Discussion

Integration of information related to climate change scenarios, spatial/temporal analysis of temperature and precipitation projections, sensitivity analysis of sectors under investigation are crucial to perform climate change risk assessment. The assessment of risk from future threats especially those due to climate change requires a suit of methods

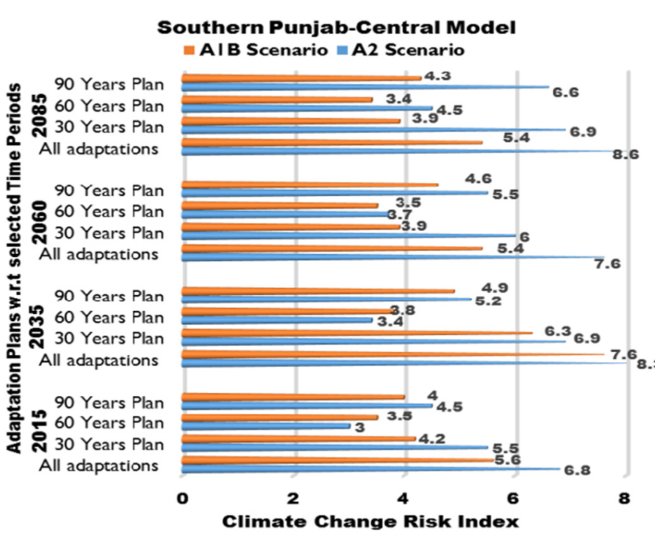


Fig. 9. Climate change risk index - central model: Maximum risk index is observed in 2085 time slice by plan including all adaptations while minimum risk index is observed by 60 years adaptation plan in 2015 under A2 Scenario. For A1B scenario, maximum risk index is observed against plan including all adaptations in 2035 time slice while minimum risk index is observed by 60 years adaptation plan in 2085 time slice. In central model projections A2 scenario is observing rasonable high risk index as compare to A1B scenario in all time periods against plan including all adaptations.

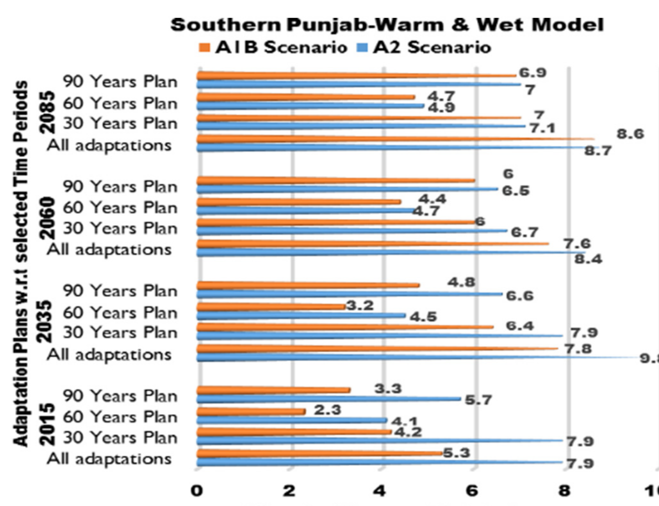


Fig. 11. Climate change risk index - warm & wet model: Under A2 scenario, maximum risk index is observed against all adaptations in 2035. Minimum risk index observed by 60 years adaptation plan in 2015 time slice. For A1B, maximum risk index is observed against all adaptations in 2085. Minimum risk index observed by 60 years adaptation plan in 2035. Risk index has moderate difference among A2 & A1B scenarios in all time periods against all adaptations.

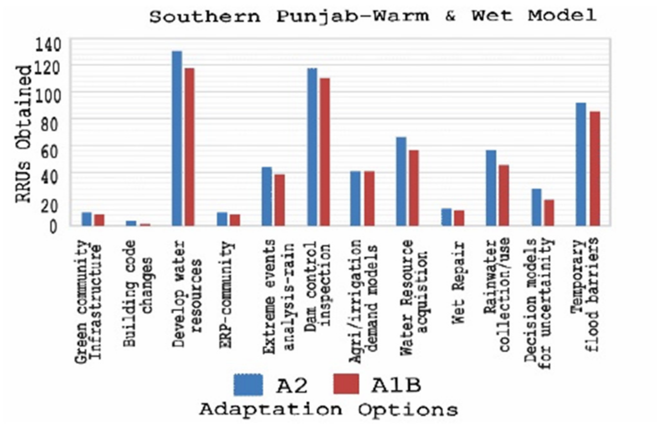


Fig. 12. Adaptation perspective – warm & wet model: In context of adaptation perspective under likelihood assessed approach develop water resources and dam/flood control inspection observed maximum RRUs for both A2 and A1B scenarios. Temporary flood barriers can serve as 3rd prioritized adaptation. All other adaptation options observed <80 RRUs and may not be supportive in achieving climate change resilience under both scenarios.

at various steps of the study to accomplish particular tasks (Aslam et al., 2017). Number of climate hazard, vulnerability and risk mapping approaches covering range of methods has been adopted by public/private authorities to accomplish desired objectives (EC, 2010). These methodologies mostly opted from the climate change impact assessment guidelines of IPCC/UNFCC in which a range of techniques are discussed. To furnish a comparative statement of such methodologies is a challenging task (Aslam et al., 2017) and their performance must be acknowledged by appropriate methods (Brown et al., 2016). In this paper, methodology is developed and well integrated at various levels from selection of climate scenarios, statistical processing of climate datasets, identification of asset considered/threat assessed to performance evaluation of defined adaptations for southern Punjab. In addition, cumulative risk assessment performed using CREAT provided climate change risk classes overlaid with sector specific data to highlight the hot spots related to climate change risk and cumulative risk over southern Punjab.

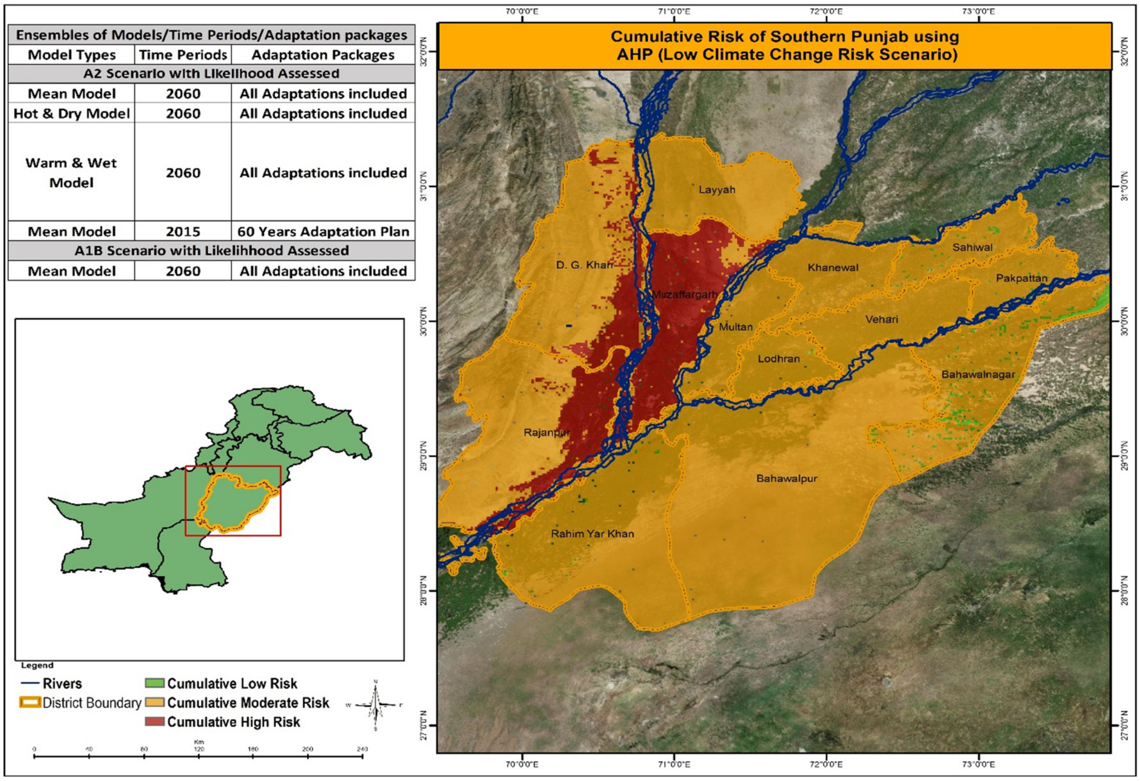
CREAT software has calculated the baseline and resilience risk in terms of RRUs through likelihood assessed approach. Risk indices for IPCC A2 & A1B scenarios are compared and tabulated in this paper. A2 scenario observed high risk index as compare to A1B for all climate models. Risk index of all climate models against all adaptation plans increases at start of 21st century (2015 time slice) and reduces till 2035. Further, in 2060 it rises and then drops in late 21st century. Baseline risk for all climate models under both IPCC scenarios is comparable which validate that CREAT risk calculations are tangible and designed experiment suits well to the investigation objective. CREAT has integrated the selected climate projections against selected adaptation plans and provided baseline and resilience risk perspective over southern Punjab. Southern Punjab has experienced sectoral damages due to frequent flooding/drought episodes in the past and this baseline vulnerability will result in increased climate change and associated cumulative risk in future. Assessing baseline vulnerability in southern Punjab is key to climate change risk assessment studies and should be performed prior to proceeding for modelled/predicted risks. Higher the baseline vulnerability, higher would be the climate change risk and ultimately higher would be the resultant cumulative risk. Risk indices presented (see Tables 4 & 5) in this manuscript are interpreted with respect to types of climate models, types of adaptation plans and time lapses of 21st century. Mean model projections of both IPCC A2 & A1B scenarios observed high risk index in all time lapses against all types of adaptation plans. Warm & wet model projections is at 2nd rank w.r.t risk index after mean model while other two models observed risk index fluxes throughout the 21st century. While interpreting risk indices with respect to adaptation plans, mean and central climate models of A2 projections are close to each other for A2 scenario in all adaptations while both observed reasonable difference from each other for A1B scenario. Warm & wet model and hot and dry model are compared as both are opposite in their nature to understand process of risk integration. Warm & wet model shows high risk as compare to hot & dry model which validates that future wet conditions (95th percentile of precipitation) may result in high risk over southern Punjab. This indication can be traced out from recent recurring of flooding episodes over area in 2014, 2012 and 2010 resulting extensive damages in all the sectors. Further under dry conditions (95th percentile of temperature) risk indices are high (>10) which indicates that climate change risk is not only associated with projections but also influenced from prevailing drought conditions and baseline vulnerability of the area. Resultant high values of risk are not pertaining to high percentiles of temperature, but they are linked with sectoral (agriculture, public health, water resources) sensitivity to 95th percentiles of temperature. Socio-economic development pattern of southern Punjab is close to the assumption/ storyline of IPCC A1B scenario therefore risk at local scale can be well described/ interpreted using A1B projections. Risk calculations presented in this investigation can be interpreted within and among climate models, time periods and adaptation plans to accomplish desired objectives. Risk indices detailed in above discourse are presented in Figs. 5, 7, 9 & 11.

Cumulative risk under defined climate change risk categories (low, medium and high) is shown in Figs. 13–15 and computed in GIS environment for analysis/ interpretation to support decisions related to climate change resilience by authorities involved in decision making and policy. Cumulative risk obtained from CREAT provided low climate change risk class, shows that district Muzaffargarh is falling in High risk category while rest of southern Punjab is experiencing moderate risk. Reasons for high cumulative risk in Muzaffargarh is increased baseline vulnerability due to high population density, food insecurity and comparatively high multidimensional poverty index. Although district Rajanpur is more food insecure and economically deprive than Muzaffargarh and Dera Ghazi Khan but due to low population density cumulative risk of these districts is moderate. Cumulative risk with CREAT provided medium climate change risk class reveals that almost 90% area of southern Punjab is under high risk category. It narrates that sectoral sensitivity has significant contribution in accretion of cumulative risk. Not only frequent climate extremes pose damages but sectoral sensitivity and baseline vulnerability also aggravate the situation. Resultant cumulative risk via overlay of CREAT provided high climate change risk class shows that about 85% and 13% area is falling in high and very high risk category (see Table 3).

Among selected adaptation plans, 60 years adaptation plan works well as compare to other plans in achieving climate change resilience as it observed minimum risk index for all climate models of A2 and A1B scenarios. Develop water resources is the most suitable adaptation to achieve climate change resilience. Dam & flood control protection and temporary flood barriers are the prioritized and preferred adaptations under wet conditions i.e. (warm & wet model and mean model) while water resource acquisition works well during dry conditions i.e. hot & dry model. Adaptation perspective has been evaluated in terms of risk reduction units and comparison of various adaptations under

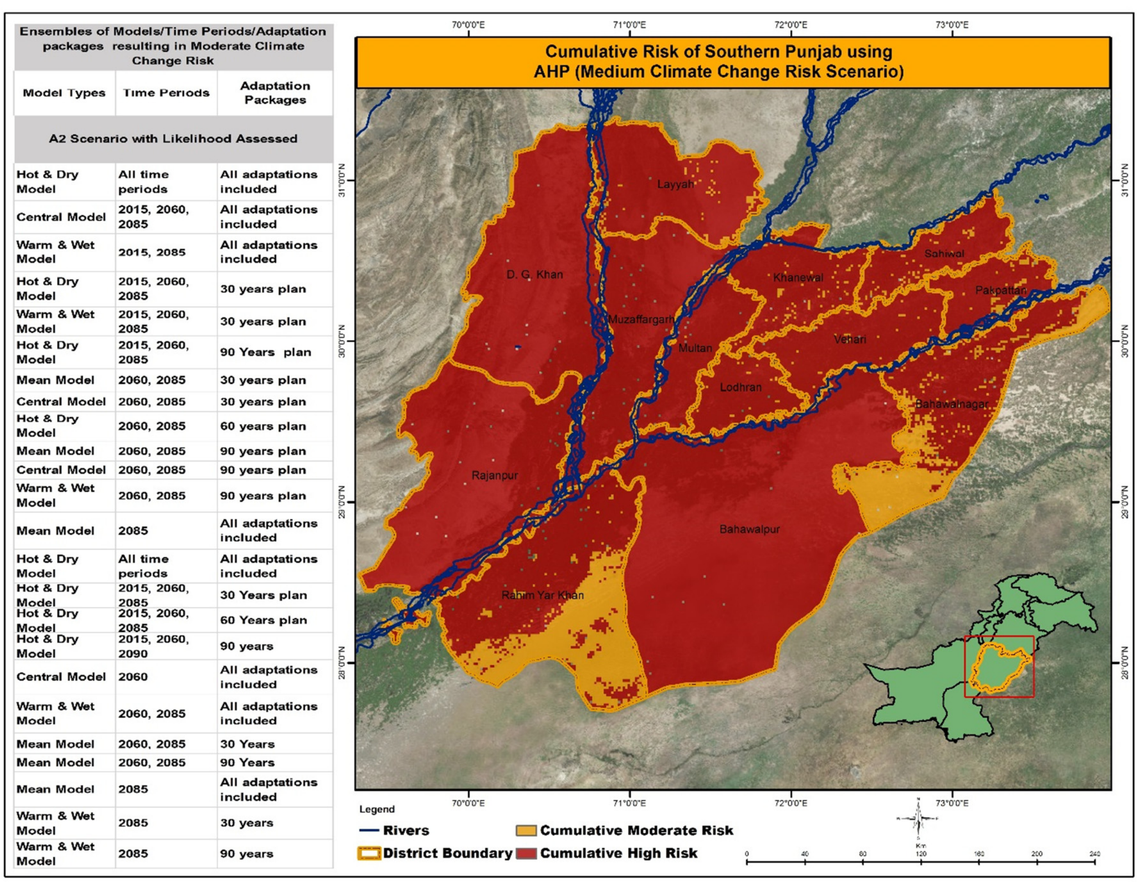
Table 3
Portion of area under cumulative risk categories.

CREAT computed climate change risk classes	GIS computed %age area under cumulative risk categories				Total area
	Low	Moderate	High	V. High	
Low climate change risk class	1.4%	85.5%	13.1%	–	100%
Moderate climate change risk class	–	9.3%	90.7%	–	100%
High climate change risk class	–	2%	85%	13%	100%



Ensembles of Models/Time Periods/Adaptation packages		
Model Types	Time Periods	Adaptation Packages
A2 Scenario with Likelihood Assessed		
Mean Model	2060	All Adaptations included
Hot & Dry Model	2060	All Adaptations included
Warm & Wet Model	2060	All Adaptations included
Mean Model	2015	60 Years Adaptation Plan
A1B Scenario with Likelihood Assessed		
Mean Model	2060	All Adaptations included

Fig. 13. Cumulative risk categories of southern Punjab with CREAT provided low climate change risk.



Ensembles of Models/Time Periods/Adaptation packages resulting in Moderate Climate Change Risk		
Model Types	Time Periods	Adaptation Packages
A2 Scenario with Likelihood Assessed		
Hot & Dry Model	All time periods	All adaptations included
Central Model	2015, 2060, 2085	All adaptations included
Warm & Wet Model	2015, 2085	All adaptations included
Hot & Dry Model	2015, 2060, 2085	30 years plan
Warm & Wet Model	2015, 2060, 2085	30 years plan
Hot & Dry Model	2015, 2060, 2085	90 Years plan
Mean Model	2060, 2085	30 years plan
Central Model	2060, 2085	30 years plan
Hot & Dry Model	2060, 2085	60 years plan
Mean Model	2060, 2085	90 years plan
Central Model	2060, 2085	90 years plan
Warm & Wet Model	2060, 2085	90 years plan
Mean Model	2085	All adaptations included
Hot & Dry Model	All time periods	All adaptations included
Hot & Dry Model	2015, 2060, 2085	30 Years plan
Hot & Dry Model	2015, 2060, 2085	60 Years plan
Hot & Dry Model	2015, 2060, 2090	90 years
Central Model	2060	All adaptations included
Warm & Wet Model	2060, 2085	All adaptations included
Mean Model	2060, 2085	30 Years
Mean Model	2060, 2085	90 Years
Mean Model	2085	All adaptations included
Warm & Wet Model	2085	30 years
Warm & Wet Model	2085	90 years

Fig. 14. Cumulative risk categories of southern Punjab with CREAT provided medium climate change risk.

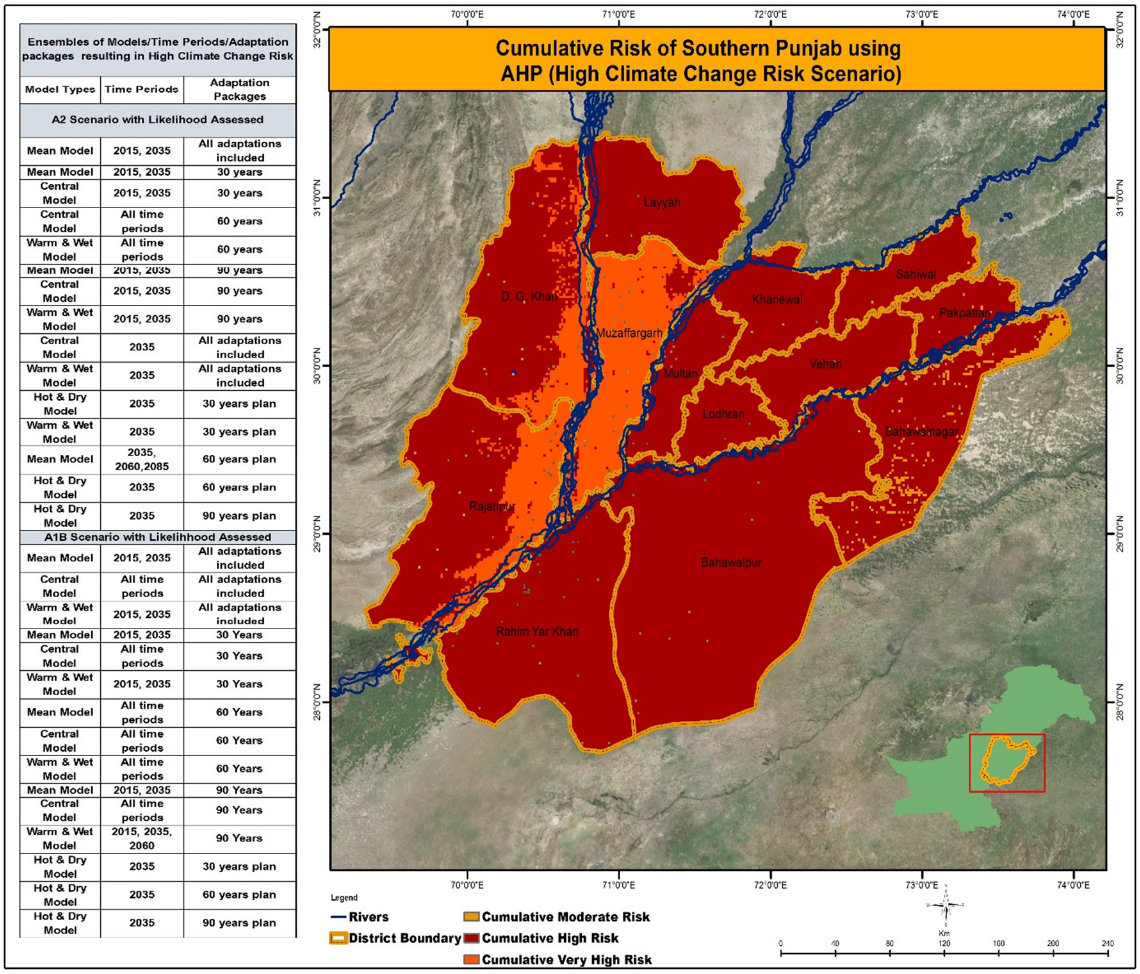


Fig. 15. Cumulative risk categories of southern Punjab with CREAT provided high climate change risk.

climate models is presented. Figs. 6, 8, 10 & 12 describe the adaptation perspective obtained and evaluated under likelihood assessed approach.

We are not aware about the predictions related to CREAT provided climate change and GIS computed cumulative risk of southern Punjab as previously such assessments have not been carried out particularly

Table 4
Climate change risk index under IPCC A2 scenario.

Model type	2015			2035			2060			2085		
	B	R	RI	B	R	RI	B	R	RI	B	R	RI
All adaptations included for individual time period												
Mean model	54.5	42.3	12.2	49.9	40.1	9.8	45.3	36.9	8.4	45.8	37.1	8.7
Hot & dry model	43.4	37.7	5.7	44.7	39.7	5	43.3	36.6	6.7	43.1	37	6.1
Central model	46.3	39.6	6.7	49.9	40.6	9.3	45.3	37.7	7.6	45.9	37.3	8.6
Warm & wet model	46.3	38.4	7.9	49.9	40.1	9.8	45.3	36.9	8.4	45.8	37.1	8.7
30 years adaptation plan												
Mean model	54.5	44.8	9.7	49.9	42	7.9	45.3	38.6	6.7	45.8	38.7	7.1
Hot & dry model	43.4	38.9	4.5	44.7	40.7	4	43.3	37.9	5.4	43.1	38.1	5
Central model	46.3	40.8	5.5	49.9	43	6.9	45.3	39.3	6	45.8	38.9	6.9
Warm & wet model	46.3	38.4	7.9	49.9	42	7.9	45.3	38.6	6.7	45.8	38.7	7.1
60 years adaptation plan												
Mean model	45.3	36.9	8.4	49.9	45.4	4.5	45.6	40.6	4.7	45.8	41	4.8
Hot & dry model	43.3	39	4.3	44.7	40.8	3.9	43.3	38.4	4.8	43.1	38.9	4.2
Central model	46.3	43.3	3	49.9	46.5	3.4	45.3	41.5	3.7	45.8	41.3	4.5
Warm & wet model	46.3	42.2	4.1	49.9	45.4	4.5	45.3	40.6	4.7	45.8	41	4.8
90 years adaptation plan												
Mean model	54.5	46.3	8.2	49.9	43.3	6.6	45.3	38.78	6.5	45.8	38.9	6.9
Hot & dry model	43.3	38.5	4.8	44.7	40.6	4.1	43.3	37.3	6	43.1	37.6	5.6
Central model	46.3	41.8	4.5	49.9	44.7	5.2	45.3	39.7	5.5	45.8	39.2	6.6
Warm & wet model	46.3	40.6	5.7	49.9	43.3	6.6	45.3	38.7	6.5	45.8	38.9	6.9

Table 5
Climate change risk index under IPCC A1B scenario.

Model type	2015			2035			2060			2085		
	B	R	RI	B	R	RI	B	R	RI	B	R	RI
All adaptations included for individual time period												
Mean model	54.5	43.3	11.2	49.9	41	8.9	45.3	36.9	8.4	45.8	37.1	8.7
Hot & dry model	43.4	38.7	5.2	44.7	39.9	4.8	43.3	36.6	6.7	43.1	37	6.1
Central model	46.3	40.7	5.6	49.9	42.3	7.6	45.3	37.7	7.6	45.8	37.2	8.6
Warm & wet model	46.3	41	5.3	49.9	42.1	7.8	45.3	36.9	8.4	45.8	37.1	8.7
30 years adaptation plan												
Mean model	54.5	45.5	9	49.9	42.8	7.1	45.3	38.7	6.6	45.8	38.7	7.1
Hot & dry model	43.4	39.2	4.2	44.7	40.6	4.1	43.3	38.8	4.5	43.1	38.3	4.8
Central model	46.3	42.1	4.2	49.9	43.6	6.3	45.3	41.4	3.9	45.8	41.9	3.9
Warm & wet model	46.3	42.1	4.2	49.9	43.5	6.4	45.3	39.3	6	45.8	38.8	7
60 years adaptation plan												
Mean model	54.5	49.7	4.8	49.9	45.9	4	45.3	40.6	4.7	45.8	40.9	4.9
Hot & dry model	43.4	39.5	3.9	44.7	41	3.7	43.3	39.4	3.9	43.1	39	4.1
Central model	46.3	42.8	3.5	49.9	46.1	3.8	45.3	41.8	3.5	45.8	42.4	3.4
Warm & wet model	46.3	44	2.3	49.9	46.7	3.2	45.3	40.9	4.4	45.8	41.1	4.7
90 years adaptation plan												
Mean model	54.5	46.9	7.6	49.9	43.6	6.3	45.3	38.8	6.5	45.8	38.8	7
Hot & dry model	43.4	39.1	4.3	44.7	40.8	3.9	43.3	38.5	4.8	43.1	37.7	5.4
Central model	46.3	42.3	4	49.9	45	4.9	45.3	40.7	4.6	45.8	41.5	4.3
Warm & wet model	46.3	43	3.3	49.9	45.1	4.8	45.3	39.3	6	45.8	38.9	6.9

Note:
B: Baseline risk (risk before adaptations).
R: Resilience risk (risk after adaptations).
RI: Risk Index (difference b/w baseline and resilience risk).

using ensembles of A2 & A1B climate models under different adaptation plans for time periods using likelihood assessed approach. To develop underlying lineages and to explore similarities current research can be appraised with other risk assessment approaches with similar methodology, ensembles of climate models and adaptation measures. Previously sector specific climate change risk assessment has been carried out by Marengo and Ambrizzi, 2006 for south America; Ahmed and Supachalasai, 2014 for south Asia; UNDP, 2004 and Dilley et al., 2005 at global scale; Merz and Thieken, 2009; EC, 2007 and EC, 2000 at regional scale. Quantum of efforts have been made in these studies to quantify climate change risk through integration of climate information, system uncertainties, exposure and vulnerability of various sectors to extreme and uncertain climate change phenomenon. Variety of risk assessment approaches in these studies has been used to accomplish desired results. To furnish a comparative statement among climate change and cumulative risk assessment studies is a challenging task and clear comparative analysis is not possible due to difference in assessment methods/approaches, selected climate models and adaptions, variation in orography and baseline vulnerability of the area under investigation.

5. Conclusion and recommendations

This paper highlight the methods to quantify climate change risk over southern Punjab and to achieve climate change resilience through performance evaluation of selected adaptations. Sectoral integrated development framework has been designed for southern Punjab to quantify climate change and associated cumulative risk. Risk indices of selected four climate models (mean, central, hot & dry, warm & wet) under assessed likelihood approaches over southern Punjab are high and there is need to put concrete efforts to deal and manage these unavoidable risks. Both A2 and A1B scenarios climate models observed risk index above 10 even after considering a suit of adaptations under different time slices. Ensembles of climate models/time periods and adaptation plans resulting in low, medium, and high climate change risk classes are identified and documented in this paper (see Figs. 13–15). Hot spots (districts) of southern Punjab under low, moderate, high and very high cumulative risk categories are identified through weighted overlay with land use, population density, MDPI and food security. About 85% of southern Punjab area falls in moderate cumulative risk category while overlaying with CREAT provided low climate change

Table 6
RRUs obtained from selected adpatations under likelihood assessed approach.

Adaptation options	Mean model		Central model		Hot & dry model		Warm & wet model	
	A2	A1B	A2	A1B	A2	A1B	A2	A1B
Develop water resources	100.3	200.8	118.7	117.3	100	93.8	130.9	117.4
Dam & flood control inspection	91.7	216	116.6	84.7	52.2	51.6	117.5	110.6
Temporary flood barriers	70.4	168.2	91.2	62.5	89.9	42.7	91.8	85.9
Extreme precipitation event analysis	34.6	104.5	43.7	41.3	23.1	22.9	44	39.2
Water resource acquisition	51.6	79.6	53.9	14	74.3	66.2	66.9	56.3
Rainwater collection & use	43.2	58.6	45.1	44.1	73.6	68.8	56.6	46.1
Agriculture and irrigation water demand models	27.4	43.4	35.8	54.9	42.6	38.8	40.8	40.8
Green infrastructure in community	8.4	20.2	10.4	2	9.9	10.4	10.4	9.1
Decision model that incorporate uncertainty	21.8	39.6	25.8	19.4	25.7	22.6	27.9	19.2
Wet repair	14.3	12.5	14.3	17.8	16.5	18	13.5	11.6
ERP-community	8.4	20.2	10.4	2	9.9	10.4	10.4	9.1
Building code changes	3.3	2.7	2	3	4.6	5.6	4.1	2.1

risk class. Whole southern Punjab is falling in high cumulative risk category except portions of Rahim Yar Khan and Bahawalnagar while overlaying with CREAT provided medium climate change risk class. District Muzaffargarh and substantial portion of district Rajanpur is falling in very high risk category while all other districts are falling in high risk category while overlaying with CREAT provided high climate change risk class.

Risk Reduction Units (RRUs) obtained from implementation of selected adaptations are directly dependent on risk assessment approach and climate models used. Dam and flood control protection and develop water resources are the preferred adaptations under warm & wet, central and mean climate models as achieved >200 RRUs. Temporary flood barriers would be helpful in achieving resilience against warm and wet model projections and not suitable for other three models as achieved <200 RRUs. Water resource acquisition can be considered in achieving resilience while considering hot and dry and warm & wet model projections. All the other listed adaptations under all the models are not feasible to consider and implement in achieving climate change resilience. Except A1B mean climate model, all the selected adaptations observed high RRUs for A2 scenario as compare to A1B scenario.

In order to achieve climate change resilience in southern Punjab, assessment of sector specific base line vulnerability to climate change is crucial. Prime focus of Government of the Punjab (GoPb) should be on development of sectors through integration of climate risk into annual development plans and other development interventions. Disaster management plans prepared by GoPb must incorporate sectors risks and required adaptations to cope with aftermath of extreme climatic events, as severe implications are reported due to poor interpretation of such risks and prevailing administrative/financial constraints. Sectoral lineages must be identified and should be addressed by decision making authorities while developing climate change resilience interventions. Also GoPb must allocate sufficient funding in annual development plans for climate change resilience and should define roles and responsibilities of line departments (irrigation, agriculture, livestock, public health engineering, food department and revenue department etc.) involved in climate change resilience for disasters preparation and management.

Early warning of floods, droughts and heat waves must be ensured. Improvement in irrigation infrastructure, water storage efficiency, rainwater harvesting, on-farm water management practices and institutional changes to promote climate change resilience are much needed in water sector development. Revised crop calendars, adoption of irrigation technologies and GMOs, climate change impact modelling of agricultural production systems, application of GIS/RS for crop monitoring and runoff farming system are measures for agriculture sector. Improvement in quality of rangelands, use of feed conservation techniques, increasing forage yield, maintaining optimal livestock densities and research on fodder varieties are suggested actions to uplift livestock sector against climate change. Improvement in sanitation conditions, increased efficiency of solid waste management, provision of mobile health units, improved potable water quality, and removing food insecurity through microfinancing are required to improve public health status of the area. Government of Pakistan/Punjab must bid international donors such as ADB, WB, USAID, DFID, JICA, SDC and GIZ to invest in building sectoral climate change resilience in southern Punjab. Awareness campaigns on climate change through active involvement of local communities, social protection and livelihood improvement, improved/revitalized access to vulnerable areas and management of socio-political adaptation implications by GoP and/or GoPb responsible departments/bodies are key decisions to develop climate change resilience. There is need to develop effective communication and awareness among disaster management bodies, international donors, NGOs and communities residing in southern Punjab. Integrated climate change risk assessment and management framework, covering sectors like water resources, agriculture and livestock, population, land use and economic status must be streamlined and focused in order to achieve objectives of adaptation investments. Implementation of such risk assessment and management frameworks should be ensured, performance should be closely monitored, and results should be communicated to develop and support national level climate change resilience agenda.

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